Planetary EDM of Micro Holes

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Abstract

Moving an electrode in planetary motion is useful particularly for drilling micro holes because flushing is difficult for a thin electrode. However, there have been few reports on such research. In the present study, therefore, the planetary electrical discharge machining (EDM) of micro holes of less than 50μm in diameter has been attempted. The results of drilling copper using tungsten electrodes show that the planetary motion of the electrode improves the material removal rate and the volumetric wear ratio, reduces the overcut and enables the drilling of deep holes. Under the experimental conditions used, the material removal rate is highest with a planetary-motion diameter of approximately 25% the electrode diameter. The volumetric wear ratio can be reduced to less than 1%, which is very small for EDM using an RC circuit. A small overcut of less than 1μm is also possible, enabling high-accuracy machining.

Key words: planetary EDM, micro hole, material removal rate, wear ratio

1. INTRODUCTION

While there is presently much demand for micromachining in industry, electrical discharge machining (EDM) is a useful method for fabricating microparts with a high precision, primarily because almost no force is exerted on the workpiece [1], and because small material unit removal can be realized. In machining microshapes, however, some problems are encountered. One of them is debris accumulation in the gap between the electrode and workpiece. This results in abnormal discharges, namely, arcs and short-circuiting, leading to unstable machining and excessive electrode wear [2, 3]. To solve this problem, some methods are employed such as planetary EDM, internal or external flushing, jump flushing, electrode rotation and ultrasonic vibration. Among these methods, planetary EDM, which is also known as orbital EDM and has been widely used in conventional die-sinking machining using CNC machines, is effective particularly in machining microparts. This is because the electrode is too small for internal flushing and because external flushing causes vibration. Adding a relative motion between the electrode and workpiece, other than the electrode feeding motion, produces a wide clearance between them for fluid circulation and then reduces debris concentration, resulting in a high material removal rate and a low wear ratio. Machining accuracy can also be improved [4, 5]. However, there have thus far been few reports on the planetary EDM of microparts. Although Yu et al. have drilled micro holes of approximately 100μm in diameter by planetary EDM [3], drilling smaller holes was not attempted and machining characteristics were not reported in detail either. In this study, therefore, drilling micro holes of less than 50μm in diameter has been carried out and machining characteristics such as material removal rate and volumetric wear ratio have been investigated.

2. EXPERIMENTAL

The drilling of micro holes by planetary EDM is carried out using a setup for micro-ultrasonic machining (ASWU-1, Creative Technology Corp.) having three CNC axes with a minimum increment of 0.05μm. The machine is equipped with an RC electrical-discharge circuit for fabricating ultrasonic-machining tools by EDM [6]. The circuit is used for preparing electrodes and drilling holes in the present experiments, as shown in Fig.1. The electrode is processed from a 300-μm-diameter tungsten rod by wire electrodischarge grinding (WEDG) [7]. The electrode material (tungsten rod) is the anode and the wire electrode is the cathode in the WEDG operation.

The drilling conditions are shown in Table 1. Copper is chosen as the workpiece material. Here the electrode is the cathode and the workpiece is the anode. No capacitor is connected to the circuit, drilling is therefore carried out only with the stray capacitance of the machine. The stray capacitance is approximately 30pF. The electrode not only revolves

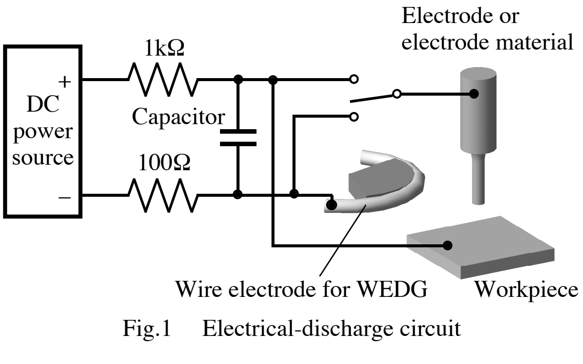

Fig.1 Electrical-discharge circuit

Table 1 Drilling conditions

Electrical-discharge circuit	RC type
Electrode material	Tungsten
Workpiece material	Copper (99.9%)
Polarity	Electrode (–), Workpiece (+)
Open-circuit voltage	50V
Electrical capacitance	Stray capacitance
Charging resistance	1.1kΩ (total)
Average charging current	3mA
Working fluid	EDM oil
Electrode revolution speed of planetary motion	9.5min^{-1}, 19min^{-1}
Electrode rotation speed around its axis	3000min^{-1}
Electrode feed per revolution of planetary motion	0.6μm–12μm, 1.2μm–24μm

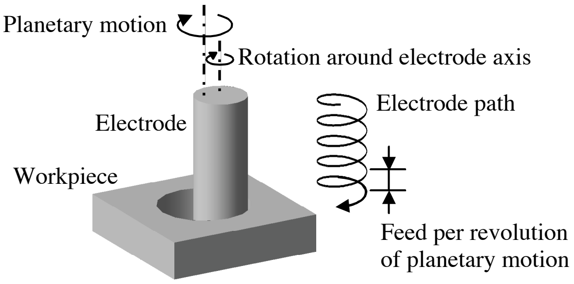

Fig.2 Planetary-EDM drilling

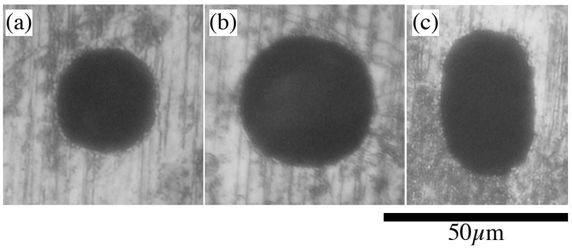

Fig.3 Microholes drilled using an electrode of 18μm diameter with (a) and (b) circular and (c) oval planetary-motion paths. The path diameters are (a) 8μm and (b) 16μm. (electrode feed length = 100μm)

around the hole axis in planetary motion, but also rotates around its axis at 3000min^{-1}. The rotation allows the electrode to uniformly wear, as well as helping in the prevention of debris accumulation. Electrode feeding is controlled by monitoring the average charging current, which is obtained from the average voltage over the charging resistance of 100Ω. The electrode is fed or retracted, with an average charging current smaller or larger than 3mA, respectively. The electrode feed per revolution of planetary motion (see Fig.2) is automatically adjusted during drilling, based on the machinability of the workpiece. It is varied in the range of 0.6μm–12μm for electrodes smaller than 20μm in diameter, and 1.2μm–24μm for other electrodes. The revolution speed of planetary motion is approximately 19min^{-1} for the former electrodes, and 9.5min^{-1} for the latter. The diameters of holes are measured by the optical microscope of a Vickers hardness tester.

3. RESULTS AND DISCUSSION

3.1. Machining Examples

One of the advantages of planetary-EDM drilling is that one electrode can be used for holes of various diameters with different planetary-motion diameters. This feature is desirable for micro holes because preparing thin electrodes is time-consuming.

Figure 3 shows examples of holes drilled with an electrode of 18μm diameter. The holes shown in Figs.3 (a) and (b) were fabricated with planetary-motion diameters of 8μm and 16μm, respectively. Noncircular holes can be drilled with a planetary-motion path other than a circular one. An elliptical hole is shown in Fig.3 (c), which was drilled with an oval path.

3.2. Material Removal Rate

Drilling was performed with various planetary-motion diameters for investigating the influence of clearance size on machining characteristics. Figure 4 (a) shows the relationship between planetary-motion diameter and material removal rate. The sum of the planetary-motion diameter and the electrode diameter (hereafter simply referred to as the sum) is 40μm, the electrode feed length is 200μm and the electrode length is 250μm. The material removal rate is calculated as drilling depth, which is electrode feed length minus longitudinal electrode-wear length, multiplied by the cross-sectional area of a drilled hole and then divided by drilling time. Without planetary motion, the electrode did not reach the feed length of 200μm, demonstrating the effect of that motion. The material removal rate increases with increasing planetary-motion diameter, and is highest at a diameter of 8μm. The clearance generated by planetary motion between the electrode and workpiece makes debris removal easier and thus machining faster. The rate decreases with planetary-motion diameters larger than 8μm. This is due to long drilling times caused by frequent short-circuiting between the electrode and workpiece, owing to the increased depths of cut of the electrode in the horizontal direction with large planetary-motion diameters.

The material removal rate for the sum of 20μm and an electrode feed length of 100μm is shown in Fig.4 (b). The electrode length is 150μm. The rate without planetary motion is also plotted in the figure at a planetary-motion diameter of 0μm because the electrode feed length reached 100μm even without it. The rate is highest at a 4μm diameter. The results shown in Figs.4 (a) and (b) demonstrate that the material removal rate is highest with a planetary-motion diameter of approximately 25% the electrode

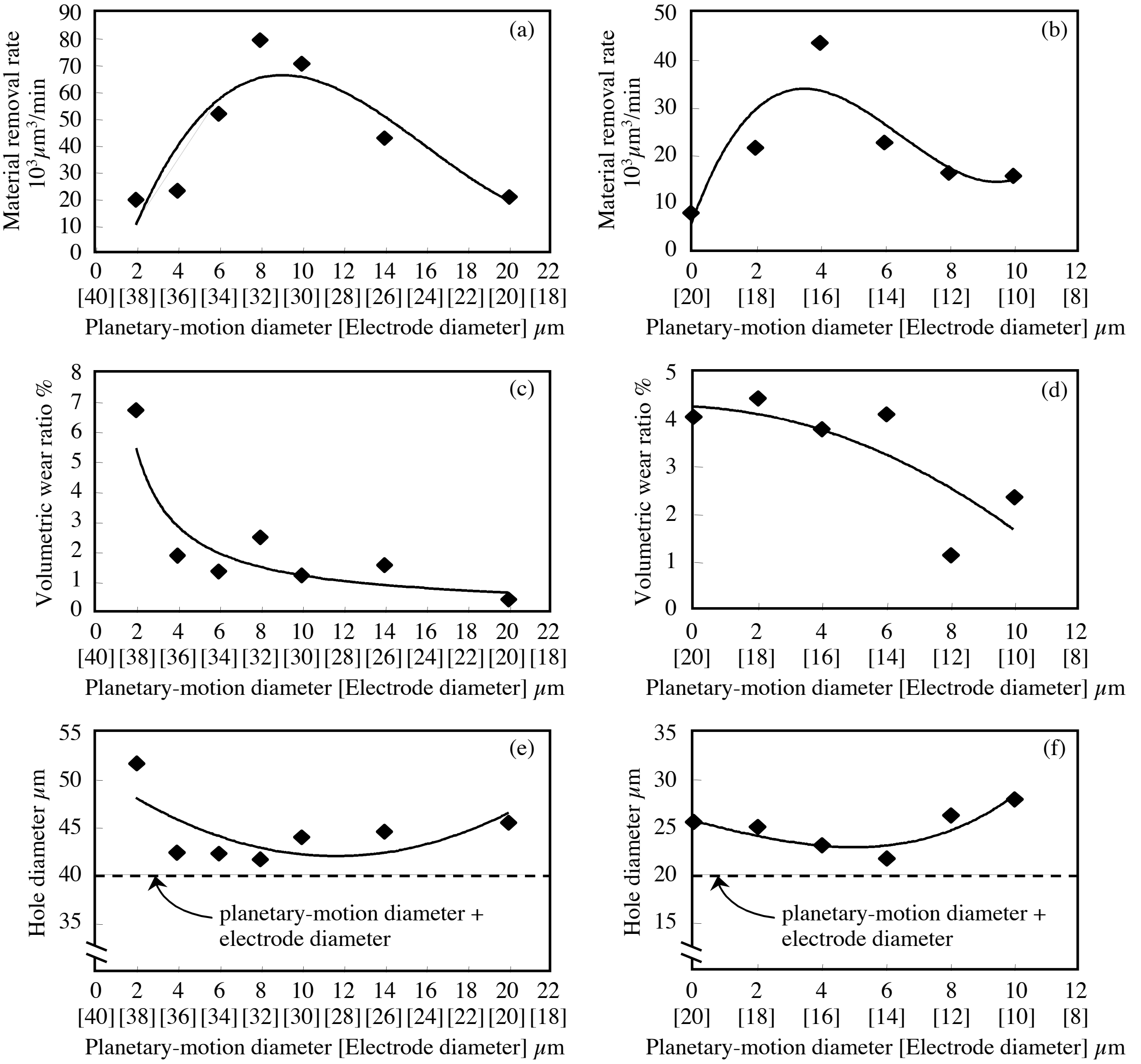

Fig.4 Drilling characteristics when sums of planetary-motion diameters and electrode diameters, and electrode feed lengths are 40μm and 200μm for (a), (c) and (e), and 20μm and 100μm for (b), (d) and (f), respectively

diameter.

3.3. Volumetric Wear Ratio

Figures 4 (c) and (d) show the relationships between planetary-motion diameter and volumetric wear ratio, for the sums of 40μm and 20μm, respectively. The volumetric wear ratio is the ratio of the electrode-wear volume to the volume of removed material. The electrode-wear volume is calculated as the cross-sectional area of the electrode multiplied by the longitudinal electrode-wear length, because there is hardly any radial electrode wear. As shown in Fig.4 (c), there is a large volumetric wear ratio of 7% at a planetary-motion diameter of 2μm. This is probably due to debris accumulation caused by the small clearance between the electrode and workpiece. The ratio decreases with increasing diameter (and clearance), and is as small as 0.4% at a 20μm diameter. In EDM with an RC-type circuit, the wear ratio is generally large and reducing it to less than 1% is a difficult task [8]. Planetary EDM shows a good performance also in reducing electrode wear. For the sum of 20μm, as indicated in Fig.4 (d), the ratio does not considerably decrease until the planetary-motion diameter exceeds 6μm, and is not less than 1% even at the largest diameter of 10μm. This result that the volumetric wear ratio is generally larger than that shown in Fig.4 (c) agrees with the result reported by Tsai et al. that the wear ratio increases with decreasing electrode diameter [9].

3.4. Drilled Hole Diameter

The size of the overcut is obtained by measuring the hole diameter. The relationships between planetary-motion diameter and hole diameter are shown in Figs.4 (e) and (f), for the sums of 40μm and 20μm, respectively. Here the hole diameter represents the entrance diameter. In Fig.4 (e), the hole diameter is 52μm for a 2μm planetary-motion diameter, and thus the overcut is 6μm. A long drilling time accounts for this large overcut, with the hole sidewall near the entrance facing the electrode

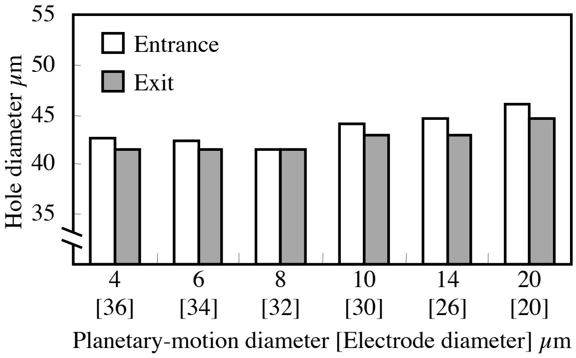

Fig.5 Entrance and exit diameters of through holes drilled in 200-μm-thick plate (sum of planetary-motion diameter and electrode diameter = 40μm)

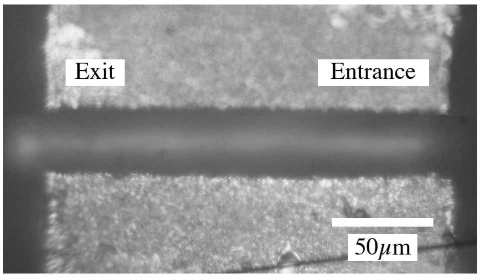

Fig.6 Longitudinal cross section of through hole drilled in 200-μm-thick plate using electrode of 32μm diameter with planetary-motion diameter of 8μm

surface all the time during machining. A high debris concentration may also be the cause of this. The hole diameter decreases with increasing planetary-motion diameter, owing to short drilling times and widened clearances. The smallest hole diameter of less than 42μm for an 8μm planetary-motion diameter indicates that the overcut is smaller than 1μm. A high machining accuracy can be realized with such a small overcut. The hole diameter increases for planetary-motion diameters larger than 8μm. Long drilling times lessen the reducing effect of widened clearances on the hole diameter.

For the sum of 20μm, as indicated in Fig.4 (f), the relationship is similar to that for 40μm. However, the overcut is smaller for small planetary-motion diameters. A possible reason for this is as follows: because of the same open-circuit voltage, the discharge gap is relatively large compared to the electrode diameter for a thinner electrode, leading to less debris accumulation preventing an increase in the overcut even with a small planetary-motion diameter.

3.5. Drilling of Through Holes

Figure 5 shows the entrance and exit diameters of through holes drilled in a 200-μm-thick plate for the sum of 40μm. The electrode was fed an additional 30μm after it penetrated through the workpiece. The hole diameters for a planetary-motion diameter of 2μm are not shown in the figure because drilling a through hole is impossible. For an 8μm planetary-motion diameter, the entrance and exit diameters are almost the same. Although they are not the same for other planetary-motion diameters, the diameter differences between the entrance and exit are less than or equal to 1.5μm, which are small compared to the hole depth of 200μm.

Figure 6 shows a photograph of the longitudinal cross section of a through hole drilled using an electrode of 32μm diameter with a planetary-motion diameter of 8μm. The diameter of the middle part of the hole is slightly larger than those of the entrance and exit. This must be addressed for fabricating straight holes.

4. CONCLUSIONS

The planetary EDM of micro holes of less than 50μm in diameter has been performed. Drilling was carried out in copper using tungsten electrodes. The following results were obtained:

(1) The planetary motion of the electrode improves the material removal rate. Under the experimental conditions used, the rate is highest with a planetary-motion diameter of approximately 25% the electrode diameter.
(2) The volumetric wear ratio can be reduced to less than 1%, which is very small for EDM using an RC-type circuit.
(3) A small overcut of less than 1μm is possible, enabling high-accuracy machining.

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